POLITECNICO
MILANO 1863

RAYLAB
DETECTING INNOVATION

spin off
POLITECNICO DI MILANO

erc

ERC-2022-PoC No. 101069171
PANTANI

NanoLab

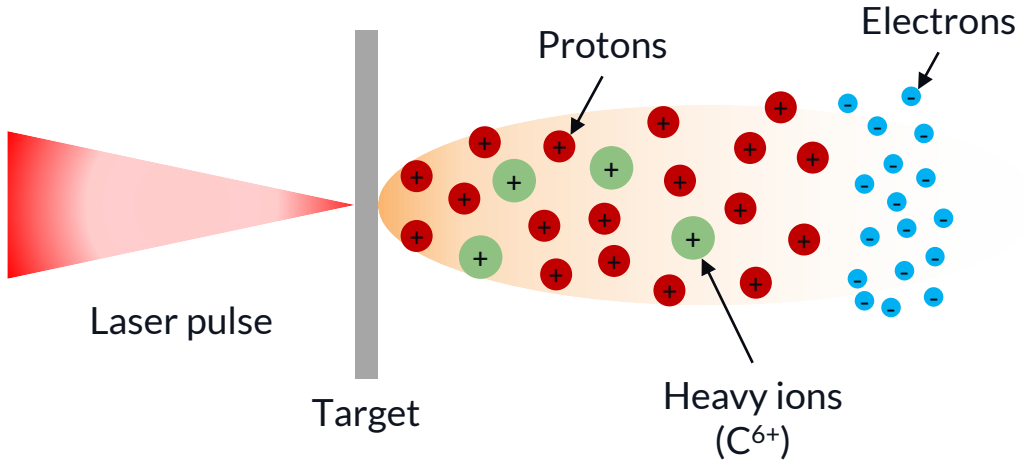
5th workshop on Beam-Line optics and Instrumentation (BLIN)

14 October 2022

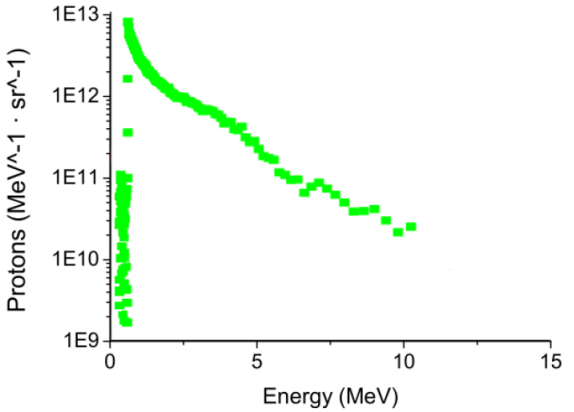
A versatile spectrometer for high repetition rate laser-driven protons

Francesco Gatti

Laser-driven proton beam diagnostics



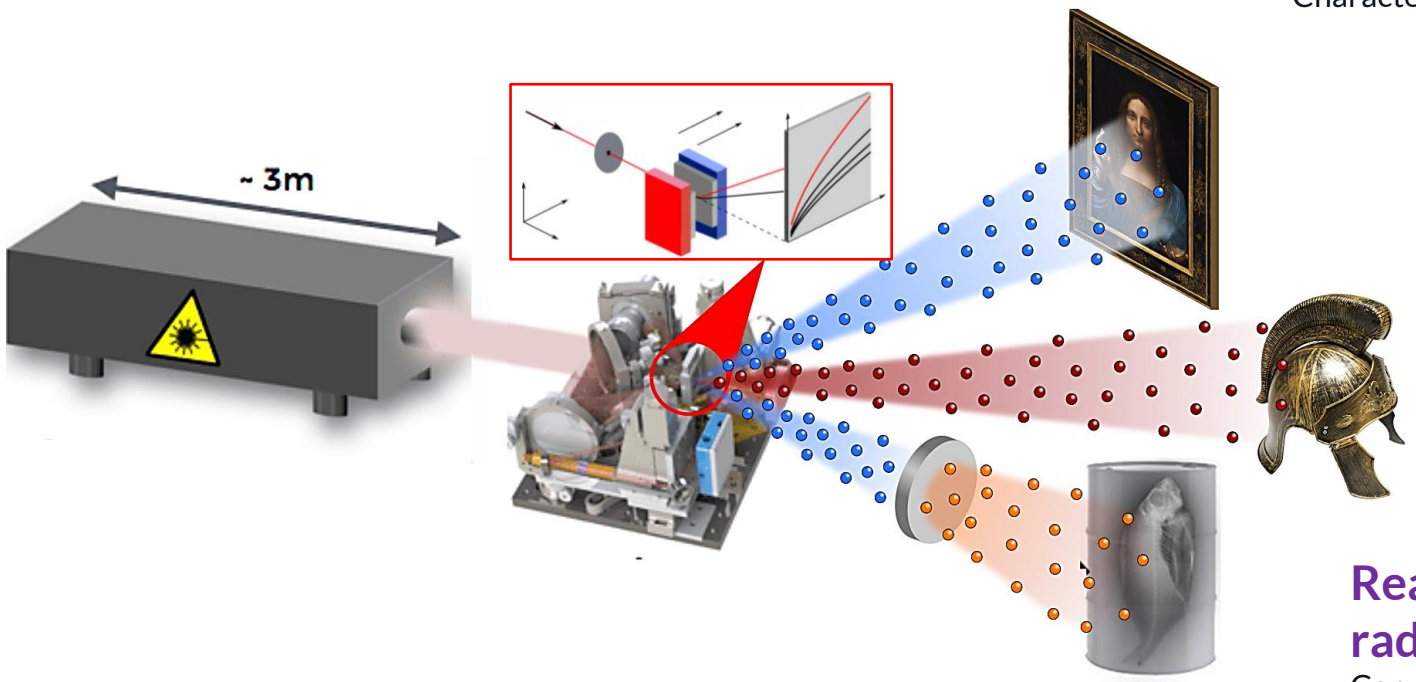
Diagnostics



[C. Zulick *et al.*, Appl. Phys. Lett. 102, 2013]

- Real-time energy spectrum (HRR)
- Discriminate ion species
- Absolute calibration
- Low background sensitivity
- EMP resistant
- No saturation

Examples of relevant applications



Particle Induced X-ray Emission (PIXE)

Characteristic X-rays emission induced by protons

Proton radiography

Proton Activation Analysis (pAA)

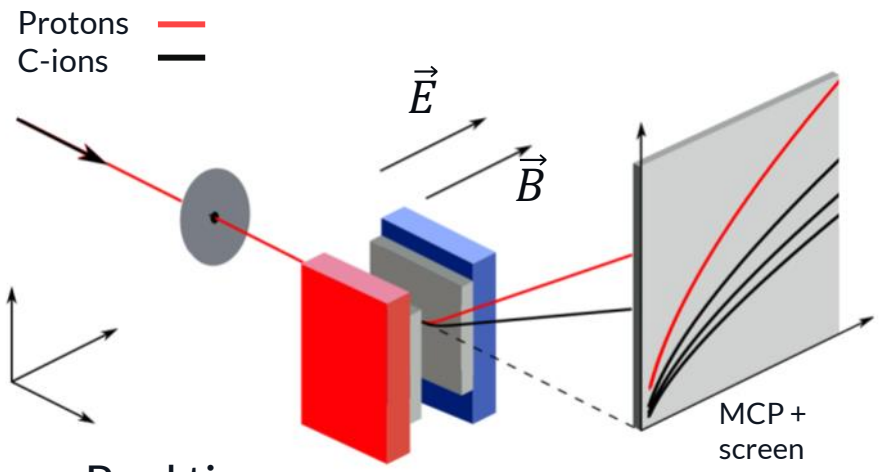
Characteristic γ-rays emission induced by protons

Reaction analysis and radiography (FNAA, FNRR)

Conversion in neutrons
Characteristic γ-rays emission
Light element mapping

Commonly used active diagnostics

Thomson Parabola Spectrometer



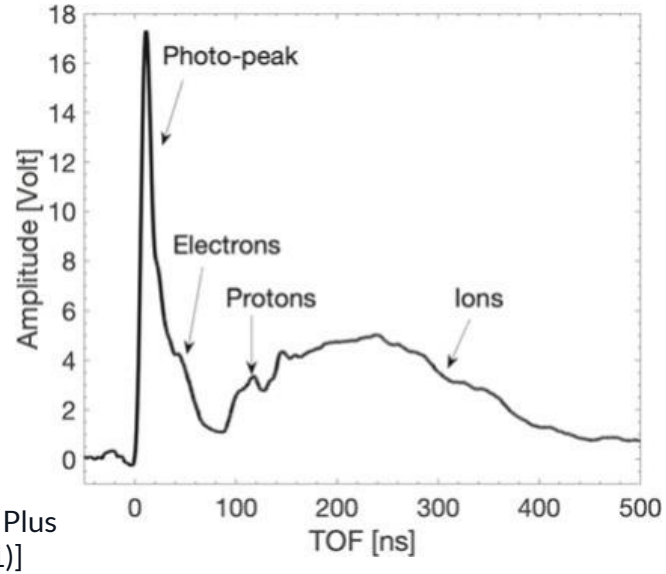
- ✓ Real time
- ✓ Discrimination of particles
- ✓ Compact

- ✗ Complex and uncertain absolute calibration
- ✗ Electric field fluctuations
- ✗ Needs position sensitive detector in 2D
- ✗ Tracks superposition

Time-of-Flight Spectrometer

- ✓ Real time
- ✓ Discrimination of particles

- ✗ Complex and uncertain absolute calibration
- ✗ Require big distances
- ✗ Complex spectrum deconvolution
- ✗ Sensitive to alignment and emp



[G. Milluzzo et al., EPJ Plus 136.11, 1170 (2021)]

Main objectives and characteristics

- Proton spectrometer → Separate signal from other particles
- Absolute calibration
- Characterization of whole energy spectrum → from < 1 MeV to > 10 MeV
- Focus on low energy rather than cut-off
- Application-oriented

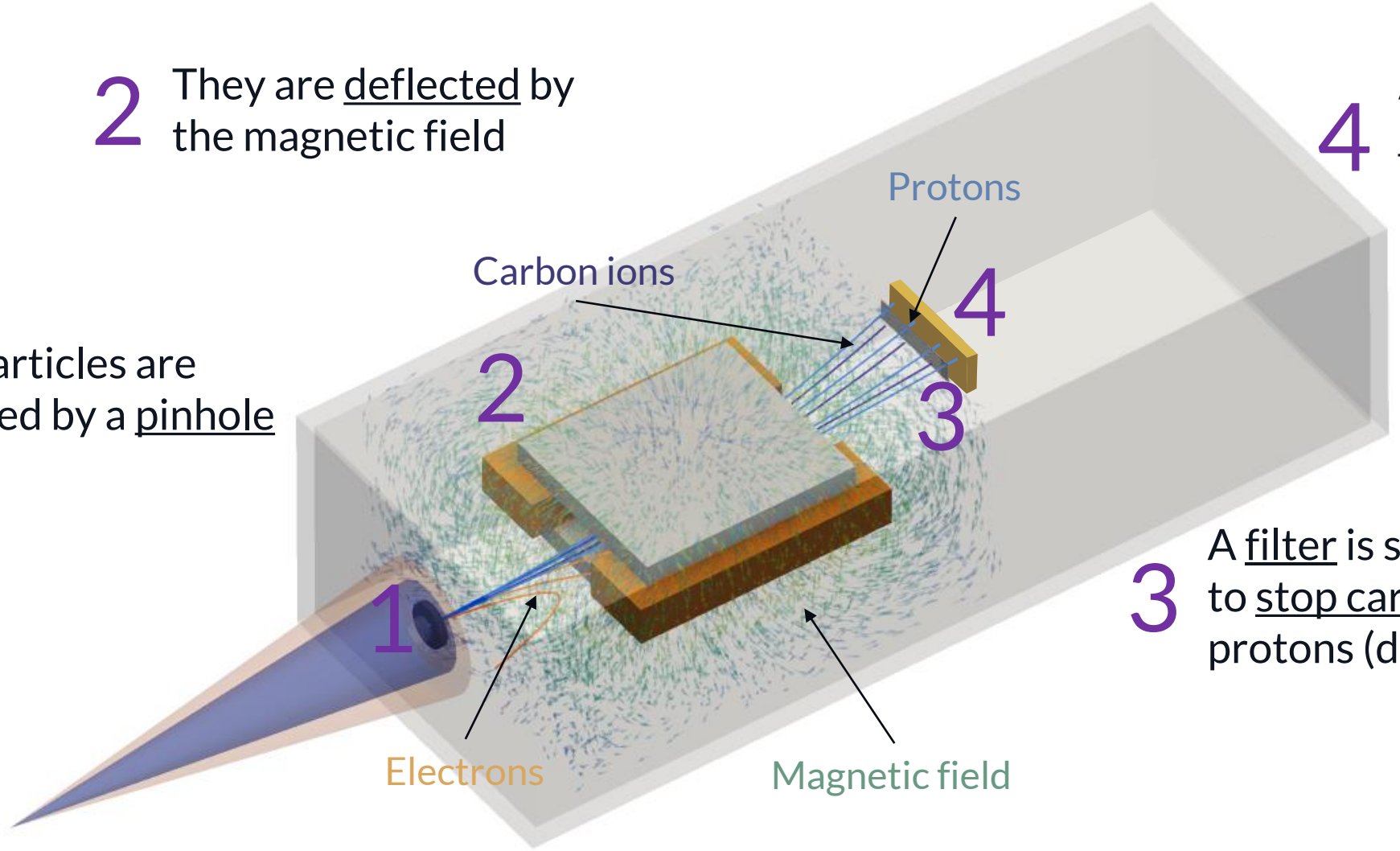
Proposed detection system

1 The particles are selected by a pinhole

2 They are deflected by the magnetic field

3 A filter is specifically shaped to stop carbon ions but not protons (differential filter)

4 A semiconductor array detects the protons



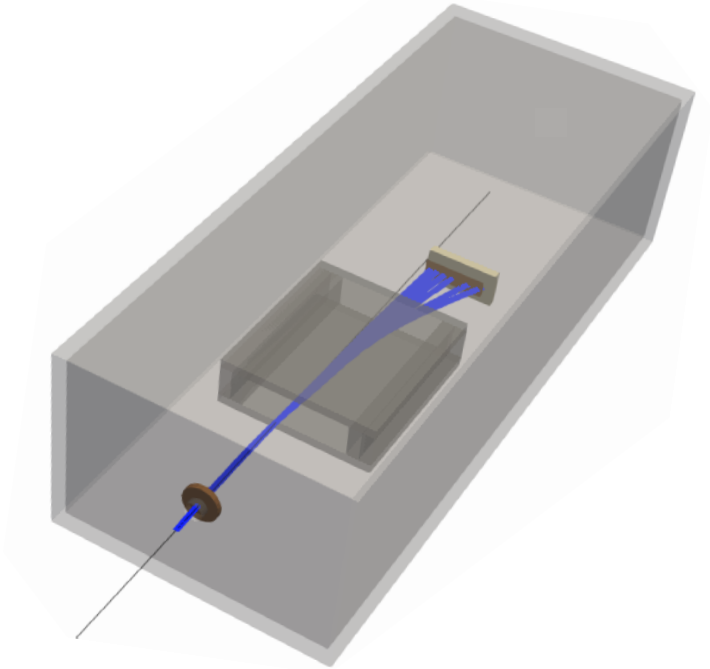
Proposed detection system

Magnetic spectrometer

- Avoid issues related to electric field fluctuations
- No fast electronics needed
- Compact
- Energy resolution lowers at high energies

Filter

- Discrimination of protons from heavy ions
- Shaped according to C^{6+} range in matter
- Added shield against EMP and X-rays

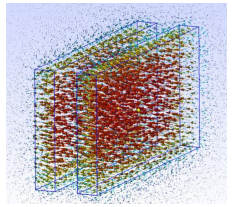


Detector

- Direct particle detection
- Thin active layer (few µm)
- 1D array (position sensitive in one direction)
- Current mode
- Range and resolution → pixels number and width

Proposed detection system: presentation outline

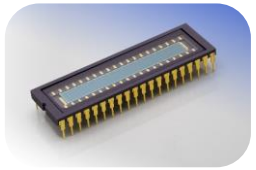
Magnetic spectrometer
- Analytical model
- Monte Carlo simulations
- Prototype device

2 

Magnet
- FEM modelling
- Experimental characterization **soon**

3 

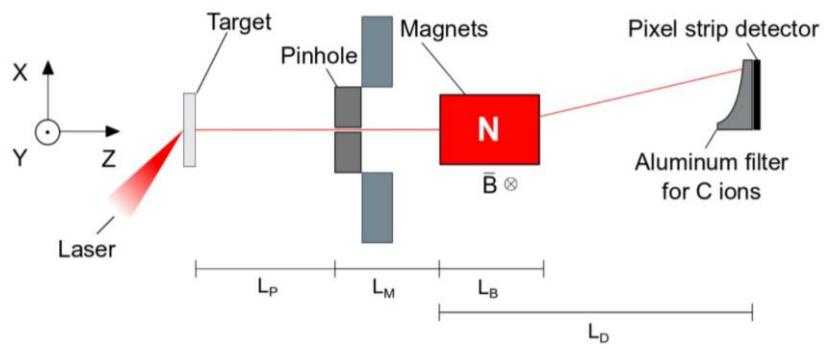
Filter
- Analytical modelling
- Experimental production

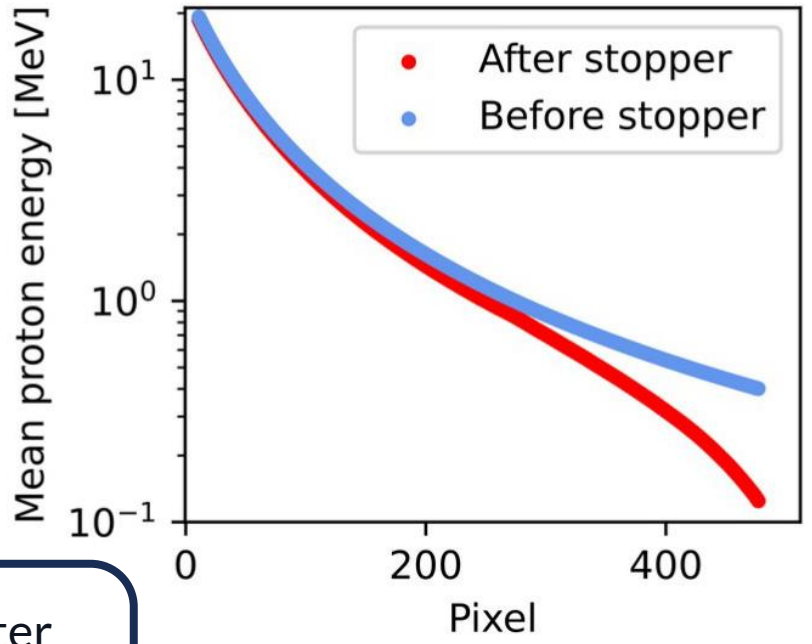
4 

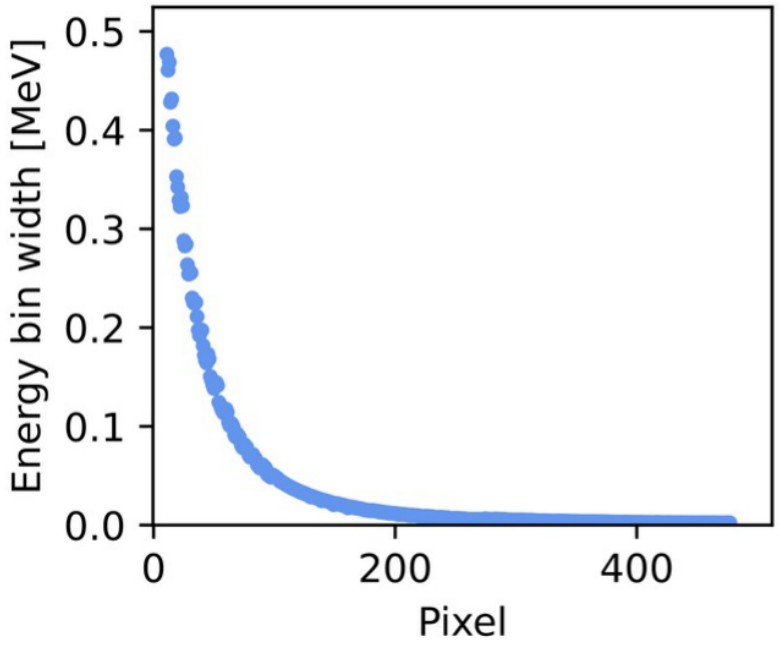
Detector
- Experimental characterization

Spectrometer model: energy bins and resolution

Analytical model + Monte Carlo analysis

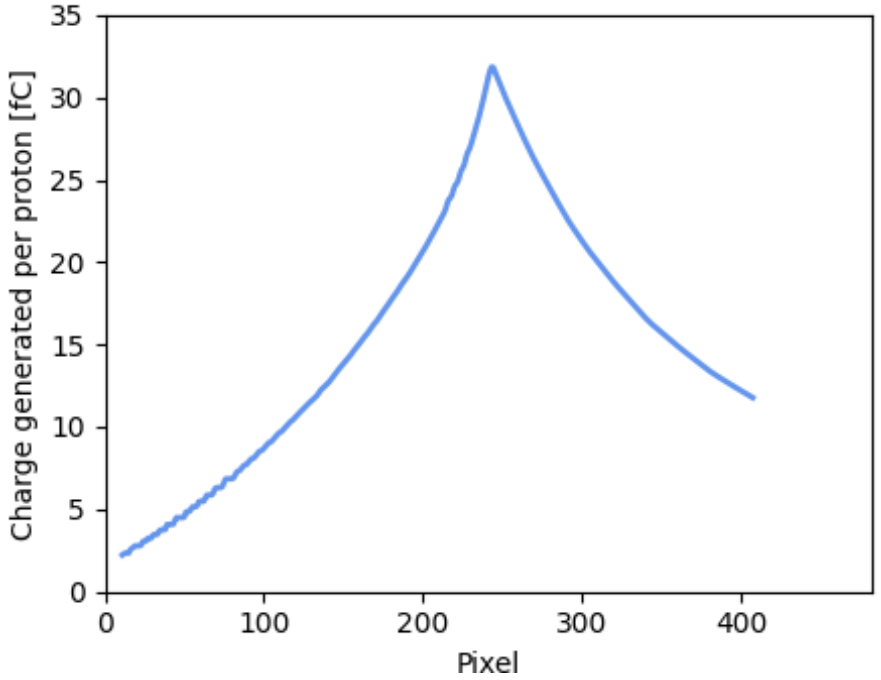


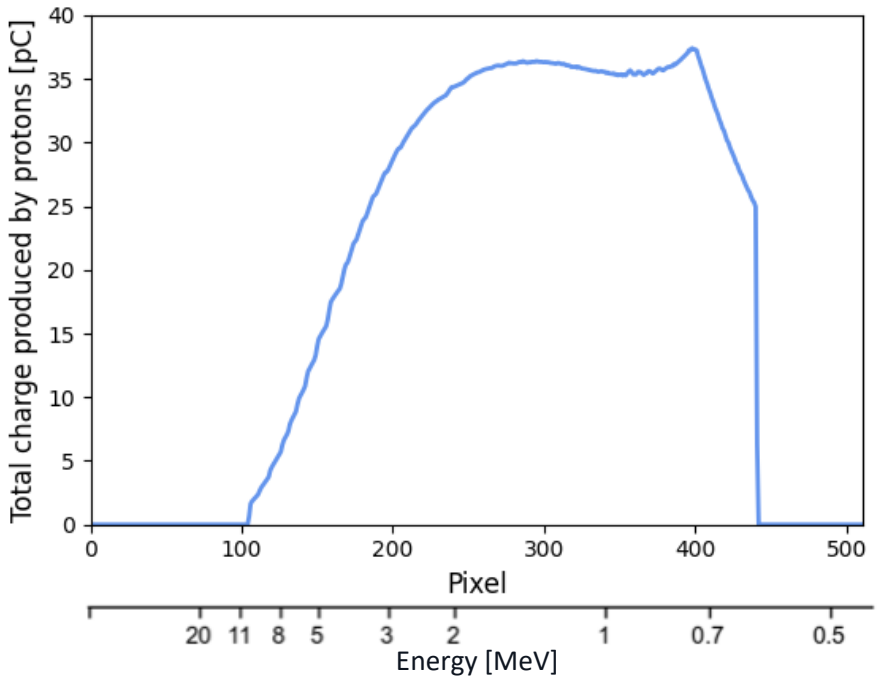




- Protons lose little energy in the filter
- Energy range 0.4 – 20 MeV
- High resolution (<3 %, 100 μm pixels)

Spectrometer model: charge collection and absolute calibration





$$\frac{Total\ charge}{Charge\ single\ proton} = Proton\ number$$

Front-end electronics

↓

Modulated capacitance

Low p energy → High charge

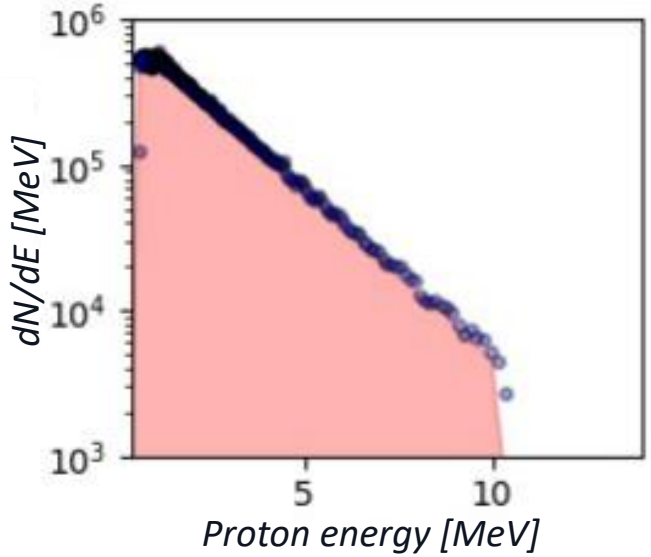
High p energy → Low charge

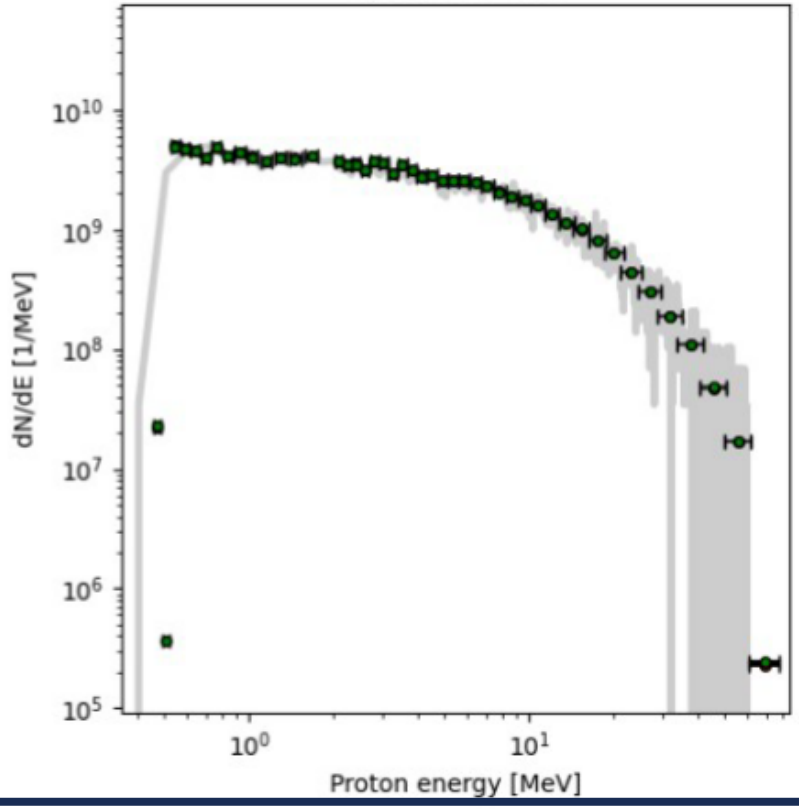
Example of spectrum reconstruction

Monte Carlo simulations

Input ⟶ Exponential proton spectrum

Output ⟶ $\frac{Deposited\ energy}{Calibration}$

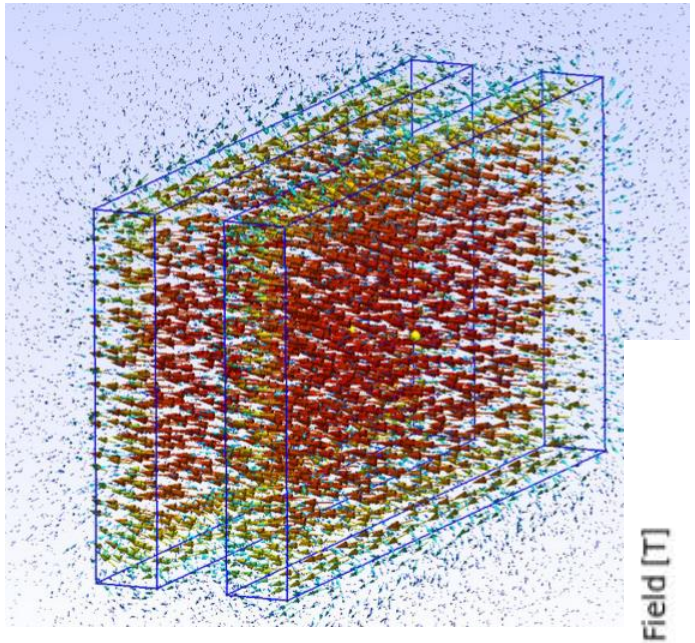




- **Good** input spectrum **reconstruction**
- Full energy range agreement
- Fewer and bigger pixels ➞ reduced resolution

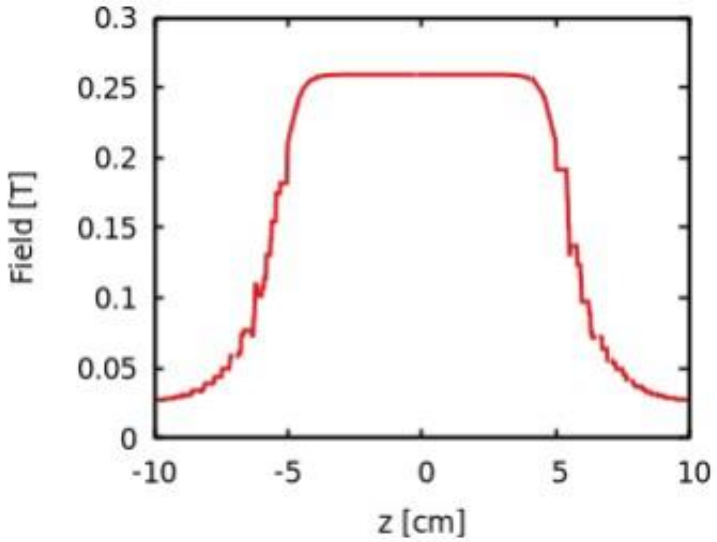
Effect of realistic magnetic field

Finite element analysis (FEM) of magnet

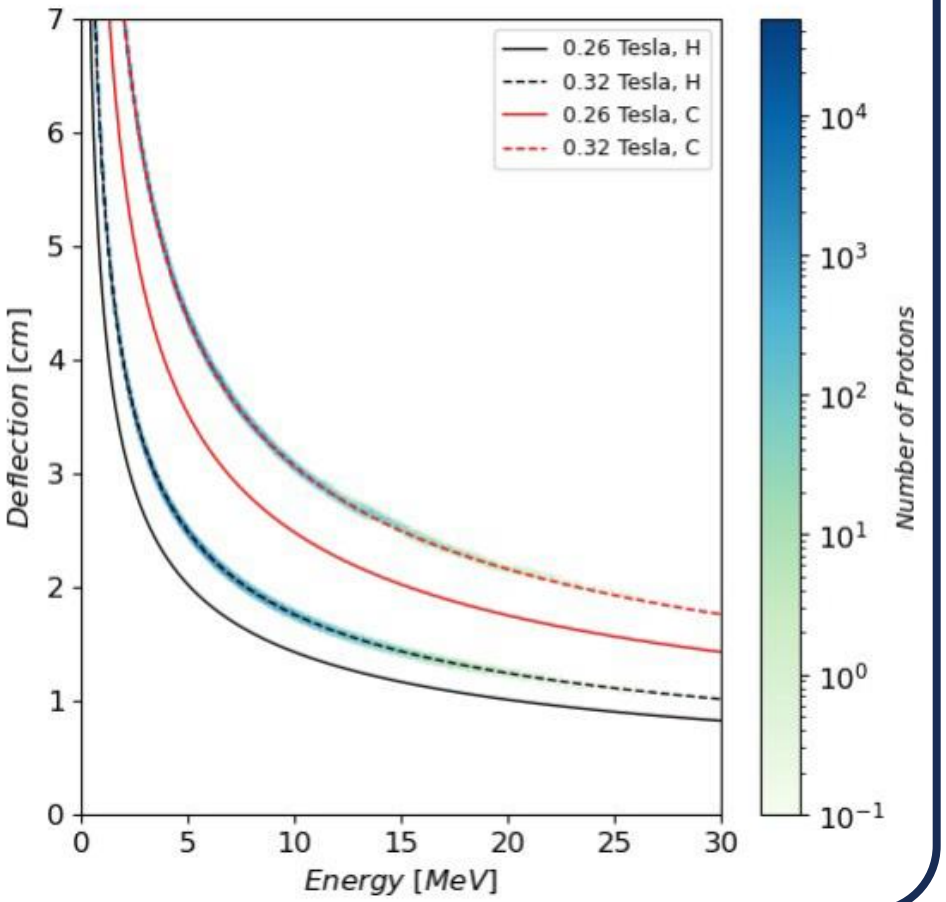


Deflection equivalent to a more intense field over the same length

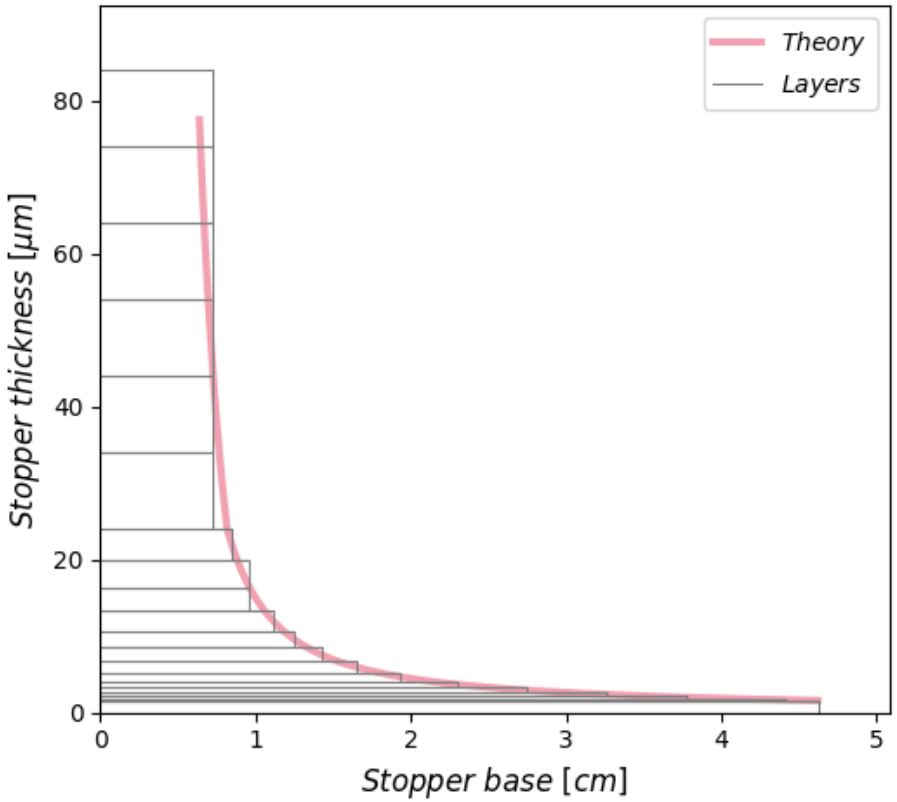
E.g. : 0.26 T ➡ 0.32 T



Monte Carlo simulations



Differential filter: requirements



Continuous analytical profile

↓

Staircase experimental realization

↓

Superposition of layers

Requirements

- Stopping power
- Robustness

Software for optimization

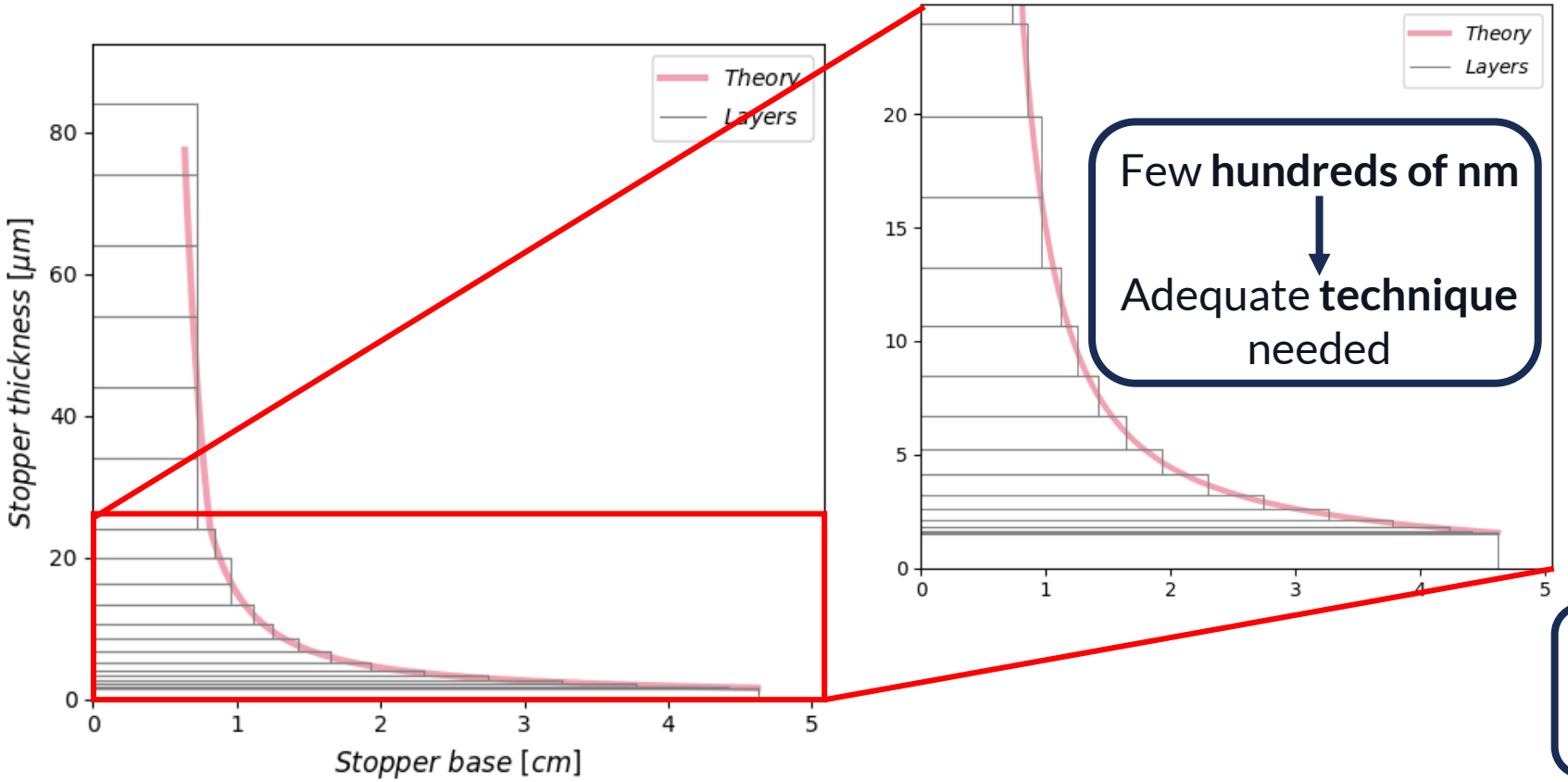
- Fixed or variable thicknesses
- Combination of materials

Constraints on:

- Lateral spacing
- Maximum thicknesses

3

Differential filter: requirements



Few **hundreds of nm**

↓

Adequate **technique** needed

Continuous analytical profile

↓

Staircase experimental realization

↓

Superposition of layers

Requirements

- Stopping power
- Robustness

Software for optimization

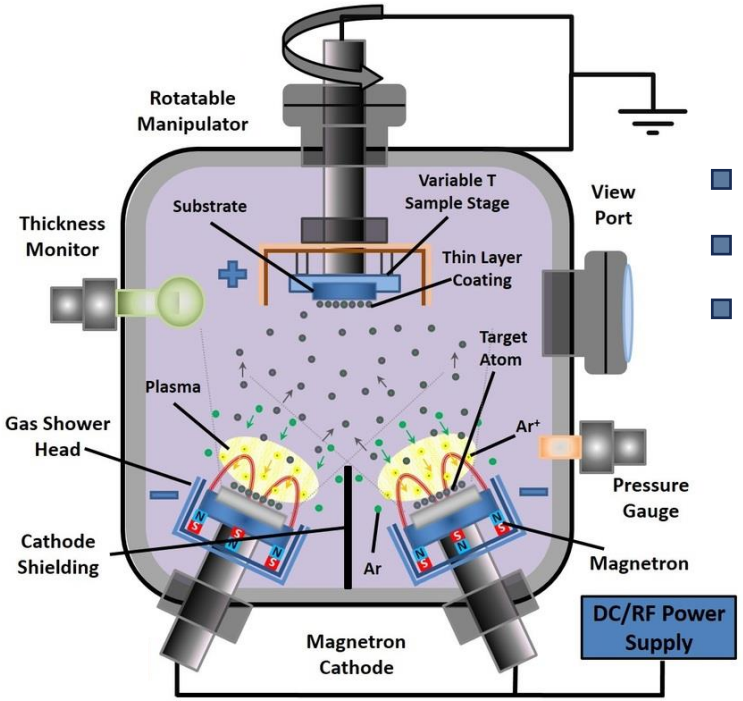
- Fixed or variable thicknesses
- Combination of materials

Constraints on:

- Lateral spacing
- Maximum thicknesses

3

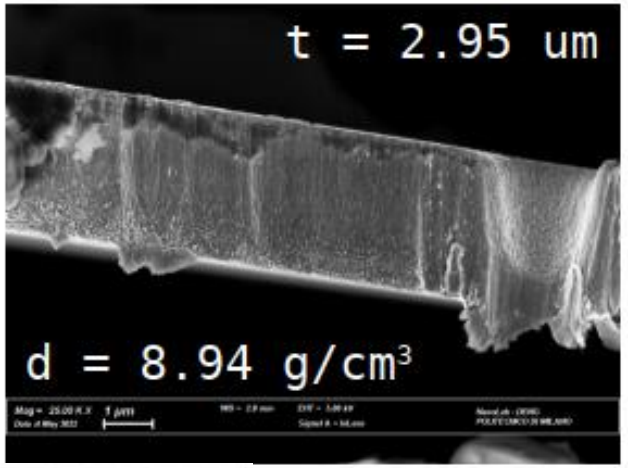
Differential filter: deposition technique

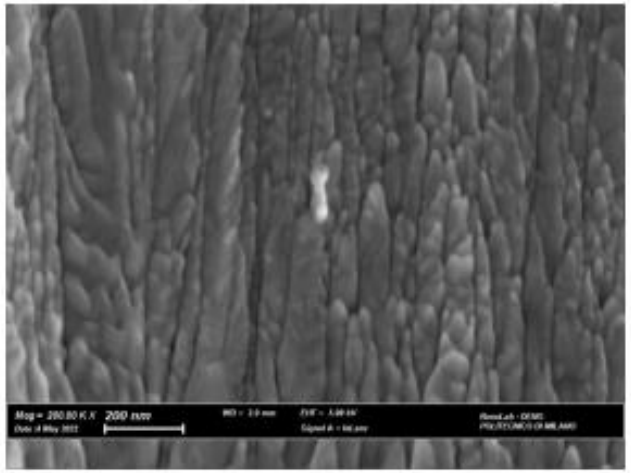


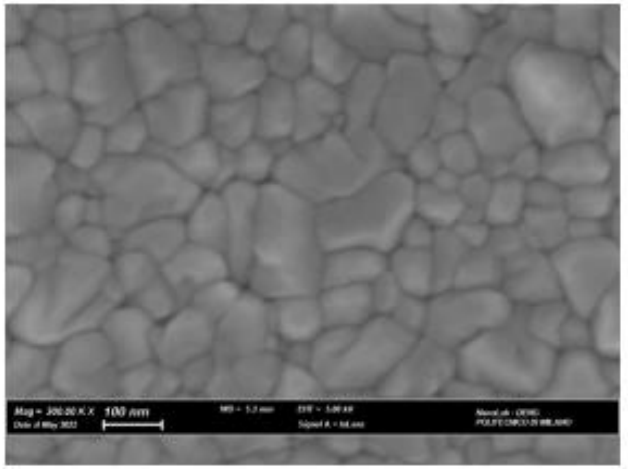
Magnetron Sputtering deposition system scheme

Magnetron Sputtering

- Physical vapor deposition technique
- Gas sputtering + plasma confinement (magnets)
- Advantages:
  - ***Flat*** *surface over large areas*
  - *Control of thickness and morphology*
  - *Compact, bulk density films*

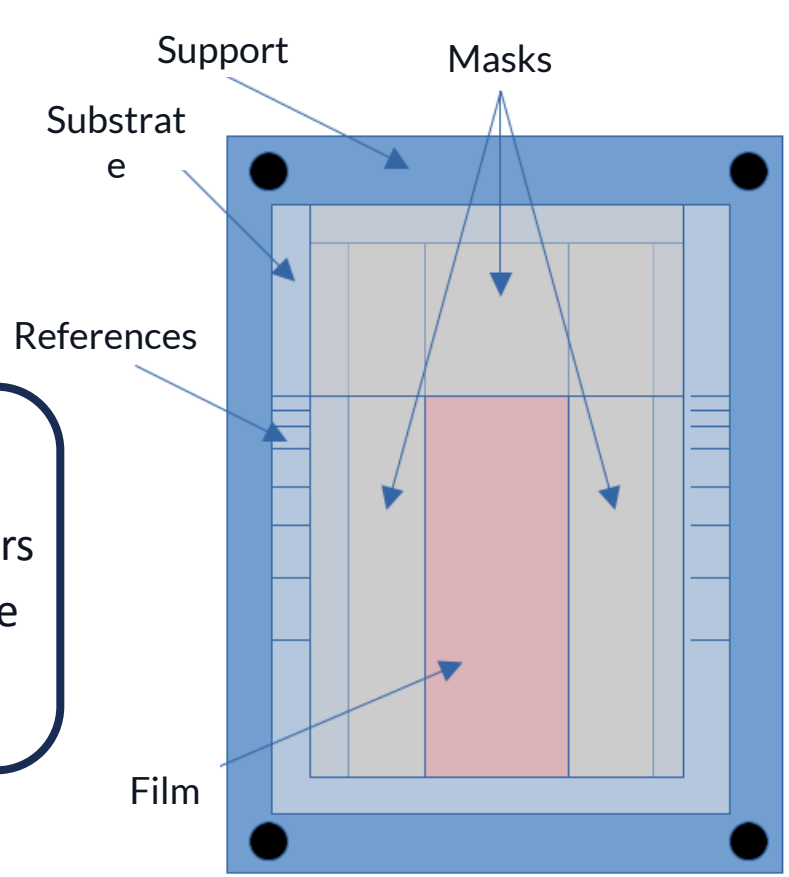


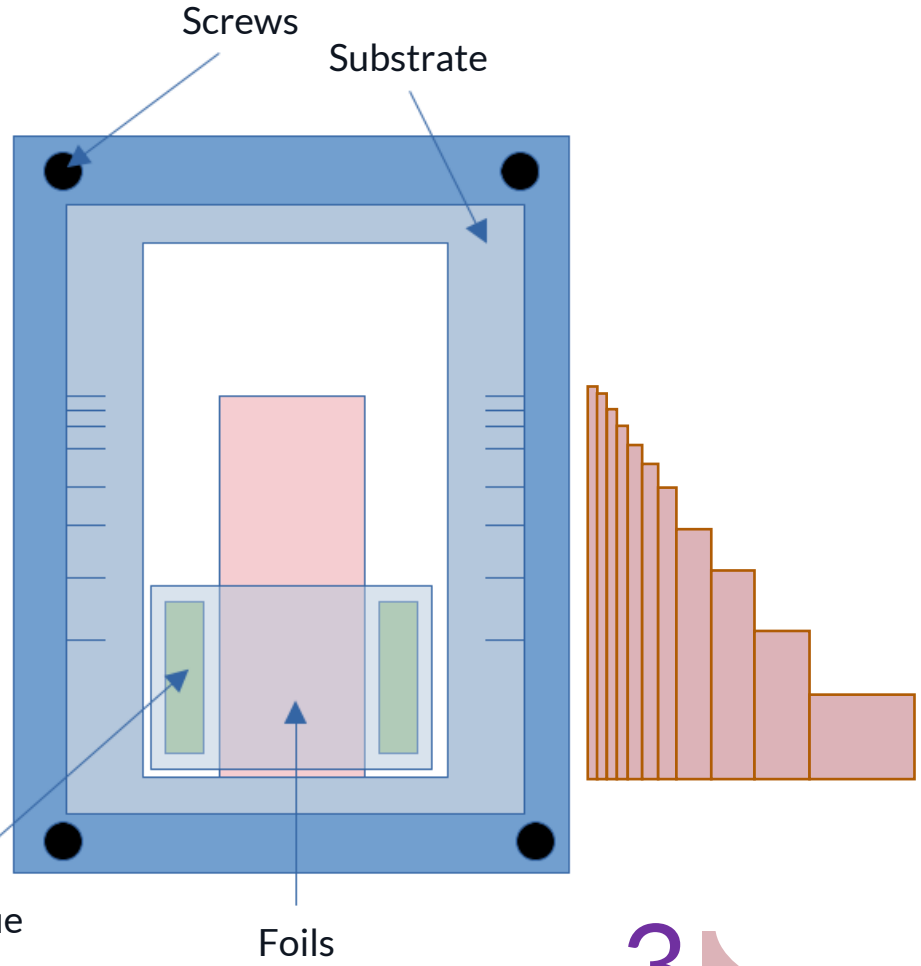




Differential filter: production strategy

- Hollow frame as support
- Masks to cover previous layers
- Graduated scale for reference
- Depositions + rolled foils





Differential filter: preliminary results

Material

Copper

29 Cu

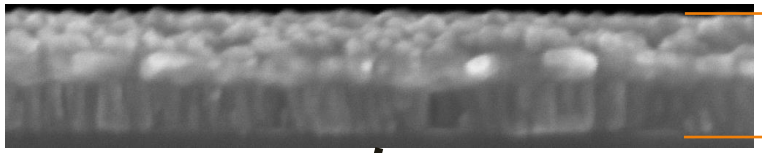
- High stopping power
- High deposition rate

29 Cu + 24 Cr interlayer (50 nm)

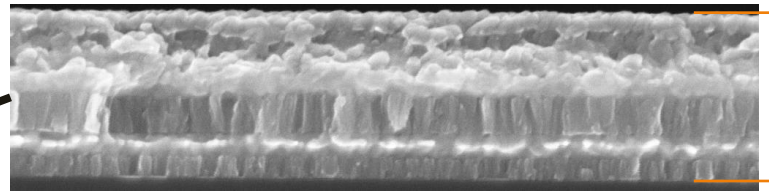
Thicknesses adjusted for the difference in stopping powers between Cu and Cr

3

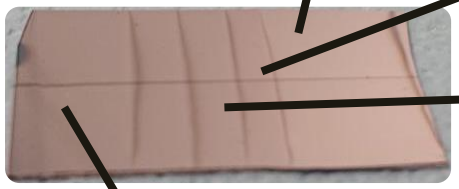
Differential filter: preliminary results

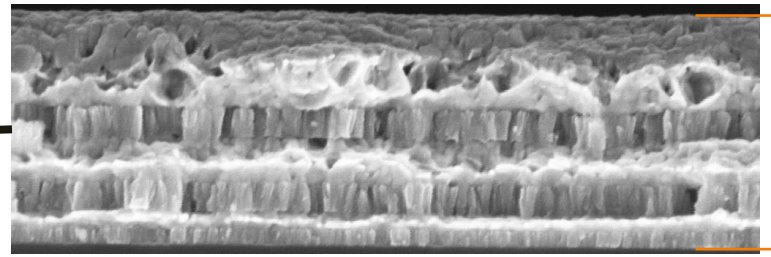


90 nm

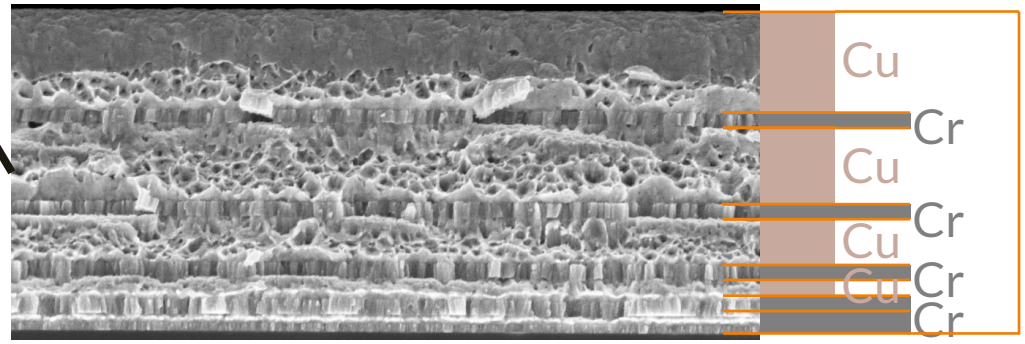


280 nm





615 nm



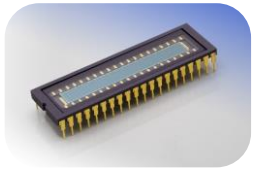
1730 nm

- 5 layers Cu + Cr
- Different morphology for the two materials
- Strong **adhesion** thanks to **Cr**
- Gradual transitions ➡ not step-like

3

Sensor characterization: alpha source

4



^{241}Am source

✚

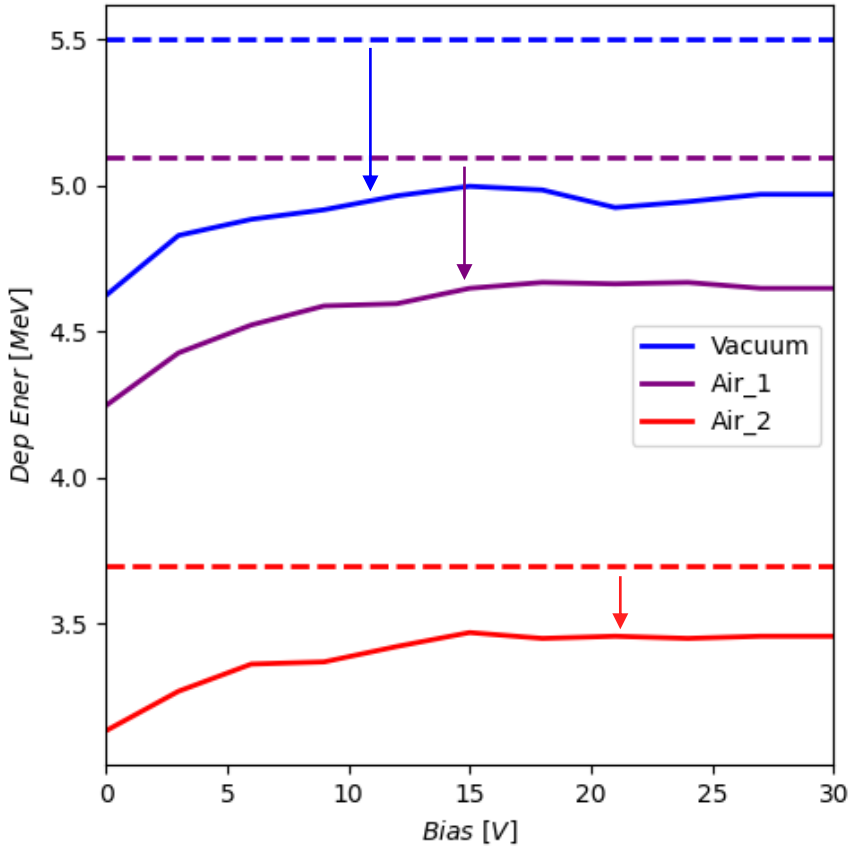
Preamplifier
Amplifier
Multichannel Analyzer

Alpha kinetic energy

Vacuum	5.5 MeV	
Attenuated by air	5.1 MeV	(4 mm)
	3.7 MeV	(3.7 cm)

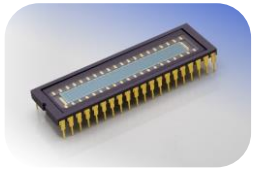
Active Thickness:
> 20 μm

Energy deposited by alpha particles



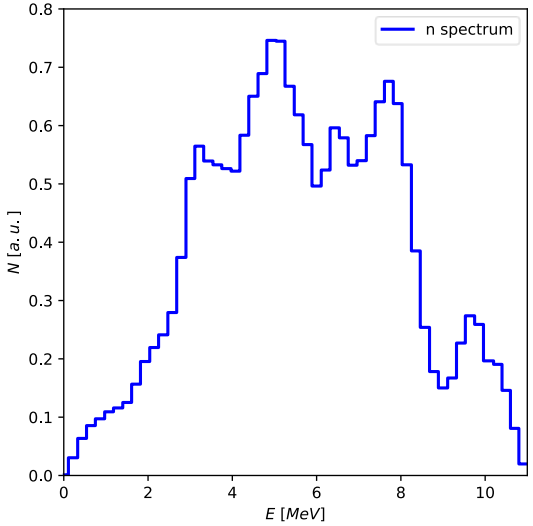
Sensor characterization: proton source

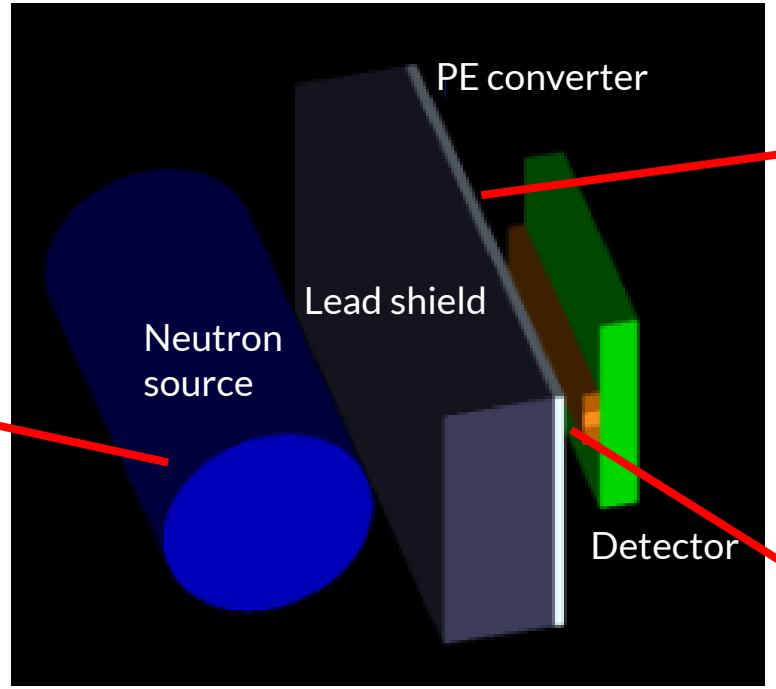
4



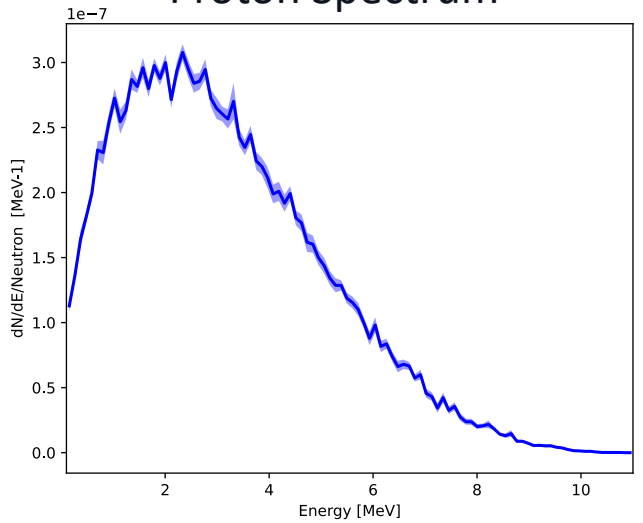
Monte Carlo simulations

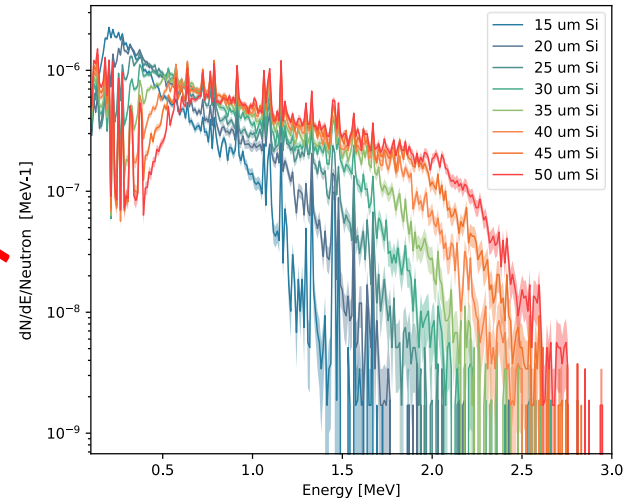
Neutron Spectrum





Proton Spectrum





Thicknesses → Spectra

Conclusions and Future steps

www.ensure.polimi.it

- Laser-driven proton spectrometer proposed
- The design seems effective
- Filter production strategy outlined
- Promising experimental results obtained
- Prototype feasible within some months

M. Passoni
Principal investigator

A. Pola

D. Rastelli

RAYLAB
DETECTING INNOVATION

Future steps:

- Production of the differential filter
- Completion of the detector characterization
- Assembly of a prototype
- Test with a controlled source
- Test with a real laser-driven source

F. Gatti

F. Mirani

erc
ERC-2022-PoC No. 101069171
PANTANI

Thank you for the attention

POLITECNICO MILANO 1863

RAYLAB DETECTING INNOVATION

spin off POLITECNICO DI MILANO

ERC-2022-PoC No. 101069171

PANTANI

NanoLab

Differential filter: alternative approach